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A Gold and Silicon Get-Together

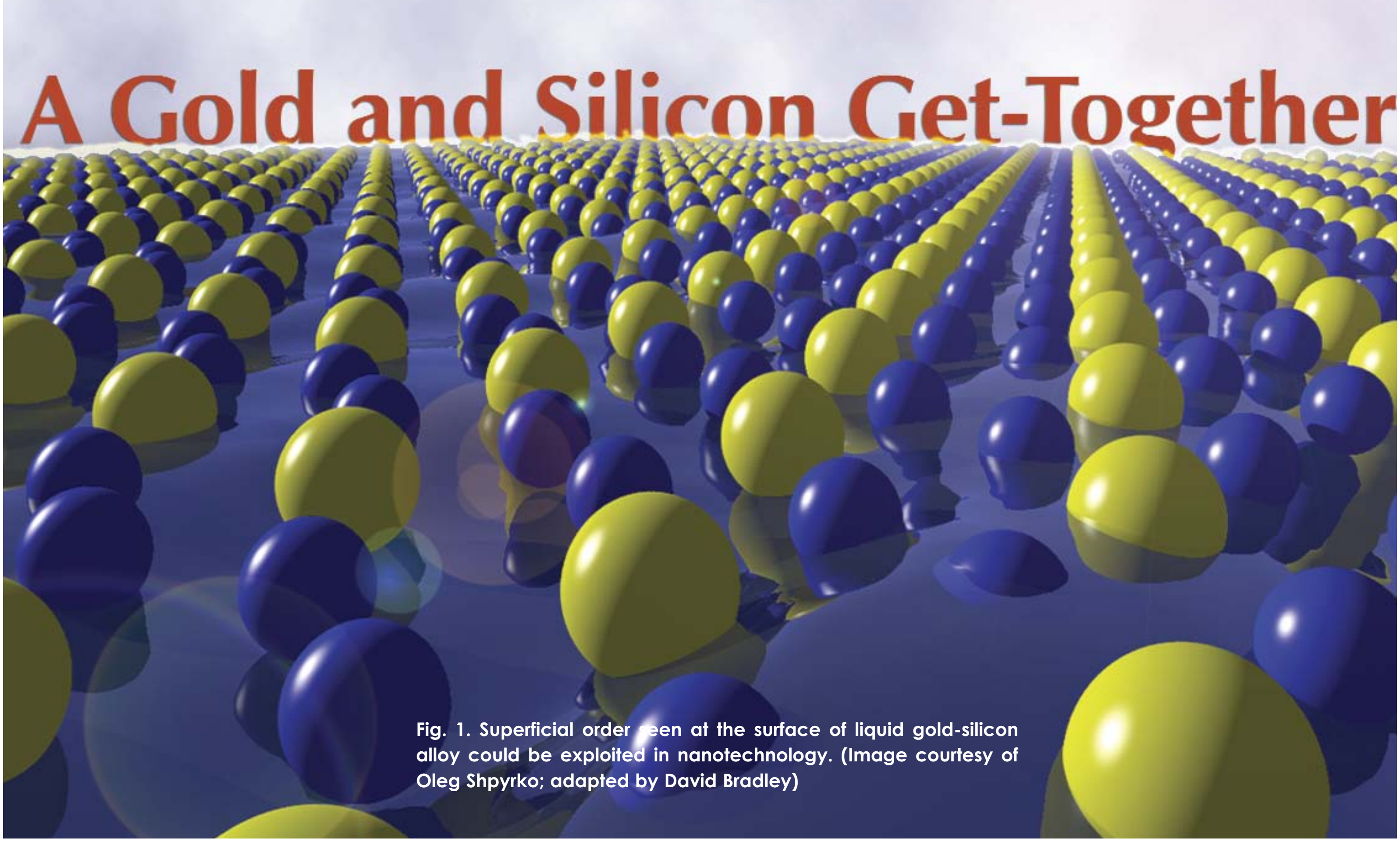

Fig. 1. Superficial order seen at the surface of liquid gold-silicon alloy could be exploited in nanotechnology. (Image courtesy of Oleg Shpyrko; adapted by David Bradley)

By definition, there is no crystalline order in a liquid. But researchers from Harvard University, Brookhaven National Laboratory, The University of Chicago, and Bar-Ilan University in Israel, using the ChemMatCARS beamline 15-ID at the APS, discovered something rather unusual when they melted an alloy of gold and silicon: the surface of this material proved to be ordered and formed a crystal-like monolayer and a structure seven or eight layers deep (Fig. 1). Such surface features might be exploited in fabricating nanoscale devices from this novel alloy and could play a role in new theories of matter that explain some of the bizarre properties of this and other composites.

Alloys often have very different properties than their constituent metals. Bronze, for instance, an alloy of copper and tin, is much tougher than either metal alone. Alloys of other metals made with semiconductor elements (such as silicon), however, have become a focus of attention for materials scientists hoping to create new designer materials for nanotechnological applications, such as gold-silicon systems for the self-assembly of silicon nanowires. Because of the low melting point of this material, it might also be useful for tightly bonding nanoscopic components that will not melt at the operating temperature of the device.

One of the reasons these new alloys are so intriguing is because of their structure and physical properties. Gold is used to make microscopic connections between components in integrated circuits, while silicon is well known as the stock in trade of the computer chip industry.

Gold melts at about 1,063º C, and silicon at 1,412º C. Mix 82 parts of gold with 18 parts of silicon to make a new type of alloy ($Au_{82}Si_{18}$), and the melting point of the composite plummets so that $Au_{82}Si_{18}$ melts at just 359º C. This in itself is not particularly unusual. Other alloys have a eutectic melting point well below the melting points of their constituent materials. However, just *how* this material melts is enabling new insights into the nature of matter.

This study shows that the behavior of $Au_{82}Si_{18}$ is different from other alloys in a critical way. The group focused on the surface of the molten alloy and found that unlike most liquids, there is some long-range order among its constituent atoms. It

is as if the surface is frozen, but the bulk of the liquid remains molten, forming a monolayer-thick crust on the surface. While a liquid-like layer on a solid surface just below the melting point is common, this inverse situation is much more unusual.

The researchers used a raft of x-ray techniques on the beamline, including specular reflectivity, grazing incidence diffraction, and diffuse scattering. Each technique exploited the intense beams available at the APS and allowed the team to extract key information about the positions of the gold and silicon atoms close to the surface of the molten alloy. The layering they observed in the alloy's surface extends three times deeper than any previously observed surface freezing.

The researchers noted that at a temperature just above the eutectic point, the alloy forms a single ordered layer just one atom thick at its surface, beneath which the gold and silicon form ordered layer upon layer of atoms, down to a depth of seven or eight layers. The origin of this unusual behavior—not seen before in any metallic alloy—may lie in the fact that in the solid state, the gold-silicon alloy does not display any order. The alloy is a uniquely glassy structure in which the atoms cannot pack neatly together as they do in other metallic alloys to form a crystalline state. However, on melting, the atoms gain the necessary freedom to arrange themselves with some semblance of order, but only on the surface where bonding between atoms is limited to the sides and below.

— *David Bradley*

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